Available online at www.sciencedirect.com

ScienceDirect

Procedia Earth and Planetary Science 11 (2015) 598 – 604

Procedia Earth and Planetary Science

Global Challenges, Policy Framework & Sustainable Development for Mining of Mineral and Fossil Energy Resources (GCPF2015)

Sustainable Development and Management of Groundwater Resources in Mining Affected Areas: A Review

Sujay Raghavendra N* , Paresh Chandra Deka

Department of Applied Mechanics and Hydraulics, National Institute of Technology Karnataka, Surathkal, Mangalore-575025, India

Abstract

Sustainable groundwater resources development refers to the efficient management of existing groundwater resources as a source of water supply to meet the needs of the present, on a long term basis in an equitable manner sustaining its quality, without negotiating the risks associated with damage to aquifer physical characteristics, storage capacity and recovery ability for future generation needs. This article discusses about various environmental impacts of mining on land, air, water, ecological disturbances and impact on socio economic fabric. In order to formulate effective, sustainable management strategies, knowledge on the behavior of groundwater systems and their interaction with the environment is very much essential. This article also aims to provide a short insight on few popular concepts of sustainability and its application on groundwater resource use and development in mining affected areas. The positive impact of sustainable management of groundwater resources in mining affected areas is highlighted in the review.

Peer-review under responsibility of organizing committee of the Global Challenges, Policy Framework & Sustainable Development for Mining of Mineral and Fossil Energy Resources.

Keywords: Sustainable management; groundwater resources development; mining; environmental impacts.

1. Introduction

Mining has both benefits and detriments to the society. The continued mining activities, perhaps welfares the local people with more employment and contributes to the development of infrastructural facilities afforded by local industry along with the enhancement of the local market. Even though the proposed mining site is in the non - forest wasteland, the surrounding areas of it may be thickly vegetated and the mining related activities impact over the surrounding vegetation and environment[1].

Groundwater occurs in a variety of aspects, depending upon the depth below land surface, rock type and topography. Groundwater is one of the prominent source of freshwater worldwide because of its high quality and perennial availability. The effects or influences of mining on groundwater regime are

* Corresponding author. Tel.: +91-9035219180;
E-mail address:sujayraghavendran@ymail.com , pareshdeka@yahoo.com

Peer-review under responsibility of organizing committee of the Global Challenges, Policy Framework & Sustainable Development for Mining of Mineral and Fossil Energy Resources.
doi:10.1016/j.proeps.2015.06.061

still poorly understood. The significant aspects of groundwater interrelated with the "hydrologic balance" are the storage capacity of rocks for ground water, the rate of movement of ground water and chemical quality. The source of water pollution is mainly from spent water from handling plants, pumping of mine water, effluents from beneficiation plants, during dust suppressing, wash off from waste and tailing dumps[2]. Groundwater occurrence is regionally very variable. Climatic conditions - precipitation especially - ascertain how much the groundwater is recharged. Groundwater usually exists even in places with very dry climates because of the nature of the local geology and the source contributing it. Sustainable management of groundwater resources can be effectively formulated and implemented provided if their spatial extent and variation through time are properly understood. Soil degradation is also one of the significant impact arising out of mining and quarrying activities wherein the land structure is altered due to excavation, stacking up of top soil and loss of land due to dumping of mine waste and overburden soil. Groundwater is very difficult to remediate and therefore the emphasis has to be on prevention of its pollution[3].

This paper attempts to provide better understanding and information about interactions of mine water with surface & ground water regimes. This article also aims to provide a short insight on few popular concepts of sustainability and its application on groundwater resource use and development in mining affected areas.

2. Environmental impacts of mining

The potential environmental impacts that can occur due to mining activities are as listed below.

2.1. Acid mine drainage formation

The waste rock and tailings formed during the processing of valuable minerals often contain sulphide minerals such a pyrite (FeS_2) that when exposed to air and water, will oxidize and release large quantities of iron and sulphate into solution. In addition, H^+ ions are liberated during the oxidation process producing an acidic solution that readily weathers and releases other trace minerals (i.e. copper and zinc) into solution. The acidic solution formed, characteristic of high metals and sulphate with low pH, is generally termed as acid mine drainage.

Acid mine drainage affects both surface and groundwater. The sources of surface water contamination are leachate from mine openings, seepage and discharges from waste rock, tailings, surface water runoff from waste rock and tailings piles and groundwater seepage[4].

2.2. Erosion and sedimentation

When material is disturbed in significant quantities, as it is in the mining process, large quantities of sediment are transported by water erosion. The sediment eventually drops out of solution and sedimentation occurs at some point downstream from the erosive source. The degree of erosion and sedimentation depends on: the degree to which the surface has been disturbed, the prevalence of vegetative cover, the type of soil, the slope length and the degree of the slope. Erosion can adversely affect soil organisms, vegetation and re-vegetation efforts because it results in the movement of soil, including topsoil and nutrients, from one location to another[5].

2.3. Fugitive dust emissions

In the process of large-scale earthwork, dust emissions are inevitably a problem. These dust particles originate from the following potential sources: ore crushing, conveyance of crushed ore, loading bins, blasting, mine and motor vehicle traffic, use of hauling roads, waste rock piles, windblown tailings and disturbed areas. Dust can contain toxic heavy metals such as arsenic, lead and other. These toxic heavy metals, when incorporated with dust can contaminate the air. Dust can also deposit in surface water causing sedimentation and turbidity problems.

2.4. Habitat modification

The large disturbances caused by mining can disrupt environments, adversely affecting aquatic habitats (i.e. lakes, ponds, streams, rivers), terrestrial habitats (i.e. deserts, grasslands, forests), and wetlands that many organisms rely on for survival. The disruption of site hydrology by large consumption or release of water, manipulation of topography, and the release of particulates and chemicals can all have indirect impacts on various habitats[6].

2.5. Surface and groundwater pollution

Water becomes easily contaminated at mine sites when it comes into contact with waste rock and tailings. Surface water and groundwater can run off site contaminating downstream water bodies with highly acidic, metal laden wastewater. Water can also become contaminated with toxic chemicals used for processing mine materials such as cyanide, petroleum products, oil, solvents, acids and reagents. Massive quantities of water are often necessary on mine sites for many operations. The most significant of these, water use for processing minerals, along with the other water consuming processes can cause drawdown of the groundwater table. Drawdown can reduce the amount of water available for recharging wetlands and surface water bodies, thereby affecting any organisms that depend on those waters[7].

3. Key groundwater management issues in mining affected areas

Mining often substantially alters the landscape in ways that affect groundwater, surface water and environmental resources. Streams, springs, and wetlands are often substantially altered or even removed from the landscape. Surface mines, by their nature, result in the removal of the landscape within the footprint of the open pit. The removal of key hydrologic landscape elements, such as sinkholes, streams and springs, may result in substantial alteration of groundwater flow patterns, quantity and quality. Once mining is completed, abandoned water-filled mines often become an asset to water resource management, given the creation of large volumes of water in storage that previously did not exist.

3.1. Issue 1: Extensive aquifer dewatering

Mining of consolidated rock and mineral deposits below the water table requires that enough water be pumped to keep the mine workings dry. The magnitude of the pumping is often very high, being equivalent to that of a small to medium size city. However, while cities usually withdraw from multiple sources that are aerially distributed, mine pumping is concentrated at the mine and strives to maintain constant drawdown of the water table. This often results in aquifer dewatering of a scale unique to mining, and causes severe impacts to springs, streams and wetlands. The reduced groundwater flow and groundwater discharge to streams (base flow) frequently results in reduced water availability to existing users and impacts to aquatic resources[8].

3.2. Issue 2: Acid mine drainage and contaminant leaching

Acid mine drainage is considered one of mining’s most serious threats to water resources. A mine with acid mine drainage has the potential for long-term devastating impacts on rivers, streams and aquatic life. Groundwater pollution can occur both directly and indirectly as a result of surface mining. Direct degradation can occur to ground water situated downhill or down gradient from a surface mine, by flow of contaminated drainage from the mine. This mine drainage can come from pits, ponds or from rainfall infiltration and ground-water flow during mining and after reclamation. Ground-water pollution would result from the same toxic overburden and coal materials that cause surface water contamination. The threat of chemical contamination may occur due to leaking underground storage tanks; and leachate from operating and decommissioned mine sites. The hydrogeologic setting can also influence the mine-drainage contamination of groundwater. Metal mines generally have the potential to generate more aggressive mine waters than coal mines[4].

3.3. Issue 3: Impacts on physical hydrogeology

When surface mines are excavated very deep, they clearly remove part of the aquifer, which in itself may represent a loss of resource or at least an increase in vulnerability for the surrounding aquifer resources (i.e. removal of the barrier to pollutants represented by the unsaturated zone). A halo of increased permeability can develop around open-pit walls, due to extensional fracturing induced by blasting and the reduction of lateral stresses. A further impact of pit lakes left behind after cessation of surface mining is that the water table tends to be steeper on the up-gradient side of the pit and more gentle on the down-gradient side of the pit, than would be the case under natural conditions. The caving-in of deep mines can be expected to cause fracturing and subsidence of overlying strata[9].

3.4. Issue 4: Impacts on local groundwater drainage, flow and discharge

The water table surface is a subdued reflection of topography and groundwater generally flows from the highland areas towards the lowland valleys and river floodplains. If the mine is located in a prominent groundwater recharge area, the recharge characteristics may get affected by the backfill material. Destruction of soil structure and micropores (decayed rootlets, worm burrows and ice wedging) also substantially reduces the infiltration rate. Natural groundwater discharge via spring flow at groundwater emergent or baseflow to streams and rivers is also affected due to alteration of topography. The mine voids could continue to act as groundwater sinks. Assuming that the pits are not backfilled at the completion of mining, pit lakes will form as groundwater inflows continue after dewatering systems are decommissioned. The contaminated groundwater baseflow can occur lower down on hill slopes and within the main valleys, where the general land surface becomes lower than the regional water table or potentiometric surface. The way in which spoil heaps are formed fundamentally influences the internal hydrogeological character of the mining site. This imparts profound heterogeneity to spoil, giving rise to strongly preferential flow mechanisms[10].

3.5. Perspectives on sustainable groundwater management plan

While groundwater management is a complex subject involving experts in geology, engineering, economics, and ecology, the primary management task boils down to a simple concept of balancing long-term supply and demand. Groundwater in mining areas is under threat from problems that affect both the quantity and the quality of water that aquifers provide. Quantity problems may arise due to extensive aquifer dewatering, impacts on local groundwater drainage, flow and discharge. Quality problems include contaminant leaching due to acid mine drainage, impacts on physical hydrogeology.

Effective management requires:

- Awareness of the status of groundwater—both its quality and the quantity available. It follows that monitoring is a prerequisite in order to identify whether problems are occurring or are likely to occur;
- Focused attention to overexploited/critical areas (Mining stressed and urban stressed Areas).
- To practice rainwater harvesting and aquifer recharging.
- Deepening and rejuvenation of wells and protecting water bodies.
- Water laws and rights in place, widely accepted and clear, or in their absence a practicable system of incentives/disincentives;
- Surveillance, to monitor adherence to regulatory measures or response to incentives/disincentives;
- Awareness in governmental planning and society at large of the importance of groundwater.

The extensive data for groundwater aquifers is an important requisite for the planning and management process and to have basic understanding of confined (deep) and unconfined aquifers in urban and rural segments. Therefore, it is significant to carryout detailed aquifer mapping involving hydrogeomorphic mapping and subsurface lithostratigraphy through well logs and geophysical findings.

Hydrogeological research and applications are needed to yield information on the concurrence and dynamics of groundwater system as a contributing factor in water resource management. There should be policy framework for using groundwater from deeper aquifers after due rethinking and framing economic extraction limits that would not damage the aquifers. There should be specific guidelines for groundwater withdrawals from urban aquifers. For sustainable water supply needs, shallow aquifer zone should be separately managed from deeper aquifers in the areas of high exploitation. Trends of over-exploitation of aquifer particularly in mining affected if observed, urgent steps needs to be implemented to enhance recharge of aquifers through rain water harvesting along with measures to promote water use efficiency. Institutional mechanism is needed to be developed for effective implementation of conjunctive use management process of surface and groundwater in mining affected areas as well as in those urban areas where groundwater quality is a problem. There is need for interagency and inter-sectorial coordination of groundwater progammes near mining affected areas to take place at various organizational levels.

Separate management goals for mining affected rural and urban areas (where groundwater is either being extensively exploited or water levels are continuously declining) should be framed. Mechanism should be evolved to periodically review groundwater situations in stressed areas. Simple and usable Groundwater Maps showing critical zones of water levels decline, over-exploitation within the stressed blocks should be prepared regularly to make the local people, user departments and the administration apprise of the alarming situations. In the Shallow Water Level areas, maps of critically water logged locations should also be prepared and made available to the concerned departments. Scientific studies/monitoring for water logging/problem of shallow water level, affecting the agricultural productivity, should also be given due place in the planning and management process of groundwater resources[11].

For the success of groundwater recharge programme, initially implementation and impact is required to be given due recognition as a promising tool for getting fruitful results. It is advisable that in mining affected areas Recharge Pit and Recharge Trench methods should be mostly taken up to protect aquifers from pollution. Direct injection/recharge well methods should not be encouraged. For rural areas, area-specific water spreading methods and on-farm techniques should be largely promoted with adequate participation of farmers. Direct recharging of aquifers from open paved/unpaved areas should not be encouraged, because of greater risk of pollution. Effective mechanism for Impact Assessment of groundwater recharge should be evolved in the state to know the techno- economic benefits of recharge programmes. Declining trend of Rainfall should be taken into consideration, while preparing area specific recharges plans. Appropriate mechanism should be developed to utilize and reuse waste water including primary and secondary treated sewage, domestic grey water and industrial effluent. In any case these should never be allowed to be discharged in any surface on groundwater body. The sustainable and socially acceptable cropping pattern for specific area based on the available resource for conjunctive use of surface and groundwater, climate and nature of soil in the area, be evolved and encouraged by respective agriculture department.

Ground Water Management Strategies needed to ensure sustainability of ground water development are (i) ground water assessment (ii) Monitoring and regulation. Salient recommendations are given as follows:

Groundwater Management leading to protection of resource should be taken up in defined geographic regions designated as “Stress Aquifers”.

- Evolve a separate ‘State Groundwater policy’ for mining affected areas and address issues of groundwater protection through preparation of well-structured “Aquifer Management Plans".
- Target case studies on: ground water development; socio-economic & cultural impacts of over extraction of ground water.
- Assessment of trans-boundary aquifers for reclamation of water logged areas.
- Water conservation and augmentation for sustainable urban development. Designating ground water management areas and defining target sustainable water yields.

4. Few case studies of sustainable development and management of groundwater

Georgios Stamatis et.al (2001)[12] investigated the impacts of past mining activities and inefficient water resources management on groundwater quality in the Lavrio area. They documented quality deterioration of groundwater leading to seawater intrusion and also nitrate pollution of agricultural origin. Maps were generated to demarcate the areas with high concentrations of heavy metals.

S. K. Chaulya (2003)[2] carried out a water resource development study near a proposed lignite mining area at Bhavnagar district of Gujarat state in India. Their study was mainly focused on assessment of water resources for the present and future, water balance status and formulation of a management and conservation strategy for the area. Their research findings suggested for Inter-basin transfer of water to artificially recharge the aquifers for the augmentation of the groundwater potential of the area to meet the future demands. In order to mitigate the heavy surface runoff loss (around 40% of rainfall, although some part of it is also utilized as consumptive used) and enhance the groundwater recharge capacity of the area, recommendations were made for the construction of suitable water retaining.

Ahmet Apaydın (2009)[13]examined the impact of sand–gravel mining, its over-abstraction and the response of the groundwater system in the Kazan Plain, Turkey. They found decline of the water table reached 15–20 m in the regions where over-abstraction had taken place. They suggest reducing the hazards to the groundwater system by immediately banning the sand–gravel pits, and implement a reclamation project thereby reducing the abstraction.

I. C. Ezekwe et.al (2012)[14]assess the regional groundwater quality and its health implications in the Lokpaukwu, Lekwesi and Ishiagu mining areas of southeastern Nigeria. Their analysis showed that iron had the highest concentration exceeding the WHO permitted desirable limit of 0.3 mg/l in about 73% of cases. Manganese was ubiquitous in groundwater samples exceeding the EU-permitted limits in about 41% of cases. Lead and cadmium occurred in 3 and 13% of cases, respectively. Their study concluded that long-term exposure to manganese and cadmium may be a significant cause of the prevalence of mental related illness in the study area. They recommend the government to embark on serious environmental education and provision of water treatment facilities to safeguard the health of the people.

Wang Li et.al (2013)[15]studied the hydrogen isotope (deuterium-δD) composition at natural abundance levels of xylem water, soil water, groundwater, river water and rainwater to evaluate whether adult plant species use groundwater and also evaluated seasonal shifts (dry/wet season) in water sources for plants growing in a semi-arid coal-mining area. Their results reveal that coal mining was significantly affecting plant growth by reducing the water supply due to decreased water table. Therefore, they suggest to protect groundwater resources during the coal mining operations in the region.

Tianming Huang and Zhonghe Pang (2013)[16]reviewed diffuse recharge studies in (semi)arid northern China, which are mainly based on environmental tracers of the unsaturated zone (chloride mass balance, natural tritium, artificial tritium, and bromine).Several suggestions based on the limited groundwater recharge rate and water table subsidence in northern China were proposed for groundwater sustainable utilization from their study.

Ayse Peksezer-Sayit et.al (2014)[17]evaluated the dewatering requirements of three open pits located in western Turkey and its impact on groundwater resources using a three dimensional numerical groundwater flow model. Their results showed that 21 years of mining did not significantly impact the water levels in the wells. However, natural discharge from the springs near the pits were about to get exhausted by the dewatering.

5. Conclusions

Groundwater management deals with a complex interaction between human society and physical environment and presents an extremely difficult problem of policy design. Aquifers are exploited by human decisions and over-exploitation cannot be always defined in technical terms. Because of large scale destruction of natural areas due to mining operations, a restoration strategy is needed as a part of the overall mining management plan. In restoration, emphasis should be given first to build soil organic matter, nutrients and vegetative cover to accelerate natural recovery process. Tree plantations can be used as a tool for mine spoil restoration as they have the ability to restore soil fertility and ameliorate microclimatic conditions. Effective plans have to be drawn to restore land affected due to mining by green belt development which would help in many ways to minimize the environmental impact. Promote sustainable and integrated land-use planning and land management practices.

References

1. J. Castilla-Gómez, J. Herrera-Herbert, Environmental analysis of mining operations: Dynamic tools for impact assessment, Miner. Eng. (2014). doi:10.1016/j.mineng.2014.10.024.
2. S.K. Chaulya, Water Resource Development Study for a Mining Region, Water Resour. Manag. 17 (2003) 297–316.
3. A. Das Gupta, P.R. Onta, Sustainable groundwater resources development, Hydrol. Sci. J. 42 (1997) 565–582. doi:10.1080/02626669709492054.
4. A. Akcil, S. Koldas, Acid Mine Drainage (AMD): causes, treatment and case studies, J. Clean. Prod. 14 (2006) 1139–1145. doi:10.1016/j.jclepro.2004.09.006.
5. G.M. Mudd, The Environmental sustainability of mining in Australia: key mega-trends and looming constraints, Resour. Policy. 35 (2010) 98–115. doi:10.1016/j.resourpol.2009.12.001.
6. G.D. Peterson, M. Heemskerk, Deforestation and forest regeneration following small-scale gold mining in the Amazon: the case of Suriname, Environ. Conserv. 28 (2001). doi:10.1017/S0376892901000121.
7. V.P. Pandey, S. Shrestha, S.K. Chapagain, F. Kazama, A framework for measuring groundwater sustainability, Environ. Sci. Policy. 14 (2011) 396–407. doi:10.1016/j.envsci.2011.03.008.

8. J. Fu, J. Jaime Gómez-Hernández, Uncertainty assessment and data worth in groundwater flow and mass transport modeling using a blocking Markov chain Monte Carlo method, J. Hydrol. 364 (2009) 328–341. doi:10.1016/j.jhydrol.2008.11.014.
9. W.L. Niemann, Hydrogeology: Principles and Practice, Environ. Eng. Geosci. 13 (2007) 86–87. doi:10.2113/gseegeosci.13.1.86.
10. W. Kinzelbach, P. Bauer, T. Siegfried, P. Brunner, Sustainable groundwater management — problems and scientific tools, Episodes. 26 (1998) 279–284.
11. R.N. Bhargava, R.S. Sinha, V. Dutta, Sustainable Groundwater Management Action and Implementation Strategies for Uttar Pradesh, Lucknow, 2010.
12. G. Stamatis, K. Voudouris, F. Karefilakis, Groundwater pollution by heavy metals in historical mining area of Lavrio, Attica, Greece, Water. Air. Soil Pollut. 128 (2001) 61–83. doi:10.1023/A:1010337718104.
13. A. Apaydin, Dual impact on the groundwater aquifer in the Kazan Plain (Ankara, Turkey): Sand-gravel mining and over-abstraction, Environ. Earth Sci. 65 (2012) 241–255. doi:10.1007/s12665-011-1087-8.
14. I.C. Ezekwe, N.N. Odu, G.N. Chima, a. Opigo, Assessing regional groundwater quality and its health implications in the Lokpaukwu, Lekwesi and Ishiagu mining areas of southeastern Nigeria using factor analysis, Environ. Earth Sci. 67 (2012) 971–986. doi:10.1007/s12665-012-1539-9.
15. W. Li, M. Yan, Z. Qingfeng, Z. Xingchang, Groundwater use by plants in a semi-arid coal-mining area at the Mu Us Desert frontier, Environ. Earth Sci. 69 (2013) 1015–1024. doi:10.1007/s12665-012-2023-2.
16. T. Huang, Z. Pang, Groundwater Recharge and Dynamics in Northern China: Implications for Sustainable Utilization of Groundwater, Procedia Earth Planet. Sci. 7 (2013) 369–372. doi:10.1016/j.proeps.2013.03.182.
17. A. Peksezer-Sayit, C. Cankara-Kadioglu, H. Yazicigil, Assessment of Dewatering Requirements and their Anticipated Effects on Groundwater Resources: A Case Study from the Caldag Nickel Mine, Western Turkey, Mine Water Environ. (2014). doi:10.1007/s10230-014-0306-4.